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Design of a high frequency generator

Electrical Engineering

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DESIGN OF A HIGH FREQUENCY GENERATOR

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BY

JOSEPH FERDINAND CHINLUND

AND

JAMES ROSS STEVENSON

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOSEPH FERDINAND CHINLUND and JAMES ROSS STEVENSON

ENTITLED DESIGN OF A HIGH FREQUENCY GENERATOR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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Introduction.

The subject of this thesis was suggested by the need of the Electrical Engineering Department for an alternator, which will give frequencies up to 1200 cycles per second, for experimental purposes. The Department expects to have the machine built, so it was thought best to take some standard machine, and change the design as little as possible. Only a small machine is needed, so it was decided to use the frame of a 5 H.P. induction motor made by the General Electric Co, and to design new stampings and windings to fit this frame, the rotor to be wound as a revolving field and the stator as the armature.

General Design.

The rotor diameter is 12", and, allowing one pole per inch of periphery, would give

37.7 poles, or say 40 poles.

$$f = \frac{pn}{2} = 20n = 1200 \text{ cycles per second.}$$

$$n = 60 \text{ R.P.S.} = 3600 \text{ R.P.M.}$$

Peripheral speed = $1 \times \pi \times 3600 = 11280$ ft. per minute.

The end connections are short, since they are between adjacent slots, and the slots are closed so this speed will not be excessive.

After several calculations it was decided to make the length of the air gap equal to 0.1", as a shorter gap made the self induction entirely too high.

Inside diameter of stator =

$$12" + 2 \times 0.1" = 12.2"$$

Circumference = $12.2 \times \pi = 38.35"$

It would not be advisable to use more than one slot per pole, as the slots would be too small, so,

$$\frac{38.35}{40} = 0.96" = \text{width of slot and tooth.}$$

Since this is a small machine, and also since the voltage can be transformed to any desired value, it was decided to generate at 100 volts.

It was found by trying larger values of current that this machine could not well be designed for an output larger than 3 K.W. So current equals

$$\frac{3000}{100} = 30 \text{ Amperes.}$$

Assume 2 effective turns per pole in stator, or 4 effective conductors per slot. By having 4 conductors in parallel this necessitates 16 conductors per slot, each carrying 7.5 amperes.

Allowing 500 circular mils per ampere, the area of each conductor should be $500 \times 7.5 = 3750$ Circular Mils.

Use No. 14 wire B. & S. gauge, the area of which is 4107 C.M.

Then,

$$\frac{4107}{7.5} = 547 \text{ circular mils. per ampere.}$$

The diameter of No 14 wire = .075" double cotton covered.

Arrange the conductors as shown on drawing, Plate 2. Then the dimensions of the slot should be

$(0.075" \times 4) + 0.08" = 0.38"$ square below wedge.

To make liberal allowance for winding, etc., it was decided to allow .02" in width and .03" in depth. So the dimensions of the slot are 0.40" wide and 0.41" deep below the wedge.

Width of tooth = 0.96" − 0.40" = 0.56"

Allowing 0.3" between poles in rotor as shown on Plate 1, the width of pole face equals 0.943" − 0.3" = 0.643"

The mean width of air gap is, then,

$$\frac{0.643" + 0.56"}{2} = 0.602"$$

Total effective turns in stator = 2 × 40 = 80 turns.

By the fundamental equation of the alternator, then,

$$E = \frac{\sqrt{2}\,\pi f n \phi}{10^8}$$

$$100 = \frac{4.44 \cdot 1200 \cdot 80\phi}{10^8}$$

Whence, ϕ = 23460 lines

Area of air gap = 0.602" × 4" = 2.408 sq. in.

The flux density then is equal to

$$\frac{23460}{2.408} = 9740 \text{ lines per square inch, or,}$$

$$B = \frac{9740}{6.45} = 1510 \text{ lines per square centimetre.}$$

With such a low density and short path through the iron, the ampere turns needed to send the flux through the iron are negligible. Hence,

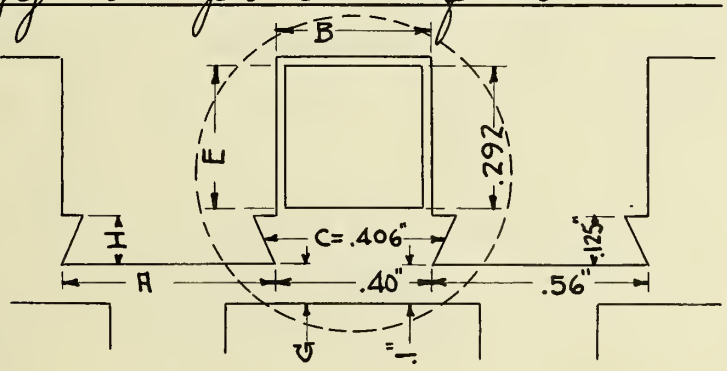
No load field ampere turns =

$0.3133 \times 9740 \times 0.1 = 305$ ampere turns.

Armature reaction $= IN = 30 \times 2 = 60$ ampere turns

E. M. F. of Self Induction.

Energy component of current.



Flux produced by F ampere turns equals

$\phi = \frac{0.47 a}{l}$ per square cm., or,

$\phi = 3.2 F \frac{a}{l}$ lines per square inch, where

a = area

l = length of path.

Referring to figure;

1. ϕ_1 = lines that go from $\frac{A}{2}$ across the air gap, through the pole face, and return around the tooth,

$$\phi_1 = 3.2\,\mathcal{F}\,\frac{A}{2 \cdot 2G}$$

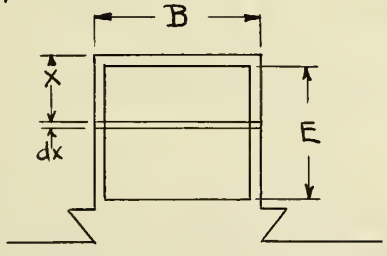
2. ϕ_2 = lines that cross the slot at H, across the mean length C,

$$\phi_2 = 3.2\,\mathcal{F}\,\frac{H}{C}$$

3. ϕ_3 = lines that cross the slot at D, across the length B,

$$\phi_3 = 3.2\,\mathcal{F}\,\frac{D}{B}$$

4. ϕ_4 = lines that cross the slot at E, across the length B. It may be seen that at the bottom of the slot the magnetomotive force will be zero, and increase to $\mathcal{F}$ at the top.



Take the element dx. The M.M.F. at this point = $\frac{X}{E}\,\mathcal{F}$, and the area = dX

The E.M.F. corresponding to this flux varies as the number of turns enclosing the flux, and that will be $\frac{X}{E}$ of the total

turns, so,

$$\phi_4 = \int_0^E 3.2\mathcal{F} \cdot \frac{x}{E} \cdot \frac{dx}{B} \cdot \frac{x}{E}$$

$$= \frac{3.2\mathcal{F}}{BE^2}\int_0^E x^2 dx = \frac{3.2\mathcal{F}}{BE^2} \cdot \frac{E^3}{3} = 3.2\mathcal{F} \cdot \frac{E}{3B}$$

ϕ_1, ϕ_2, ϕ_3, and ϕ_4 are all in lines per inch of length, so they will all have to be multiplied by the effective length of the iron

$$l' = 4 \times .9 = 3.6''$$

Adding 0.4" for end connections,

$$l = 3.6'' + 0.4'' = 4.0''$$

$$\Phi = (\phi_1 + \phi_2 + \phi_3 + \phi_4) l$$

$$\Phi = \sqrt{2} \cdot 3.2 (\text{effective ampere conductors}) \left(\frac{A}{4G} + \frac{H}{C} + \frac{D}{B} + \frac{E}{3B}\right) l$$

$$= \sqrt{2} \cdot 3.2 \cdot 60 \cdot 2 \left(\frac{0.56}{0.4} + \frac{0.125}{0.406} + \frac{0.06}{0.4} + \frac{0.292}{1.2}\right) 4.0$$

$$= 544 (1.4 + 0.308 + 0.15 + 0.243)\, 4$$

$$= 544 \cdot 2.101 \cdot 4 = 4575 \text{ lines.}$$

E.M.F. of self induction =

$$E = \frac{4.44 f n \Phi}{10^8} = \frac{4.44 \cdot 1200 \cdot 40 \cdot 4 \cdot 4575}{10^8} = 39.0 \text{ Volts.}$$

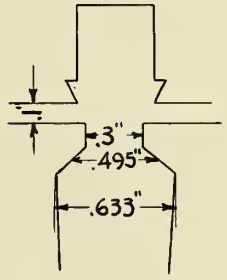
The reactance of self induction then equals

$$X = \frac{39.0}{30.0} = 1.3 \text{ ohms.}$$

This is the inductive reactance due

to the power component of the current. But the wattless component reaches a maximum between poles, so ϕ_1 will have to cross the air gap twice and also cross an air gap between the poles, the mean length of which is,

$$\frac{0.495+0.3}{2} = 0.392"$$



Total gap $= 0.392" + 0.2" = 0.592"$

So,

$$\phi_1 = 3.27\frac{A}{2 \cdot 2G} = 3.27\frac{0.56}{2 \cdot 0.592} = 0.473$$

All other factors remain the same, so,

$$\Phi = 544(0.473+0.308+0.15+0.243)4.0$$

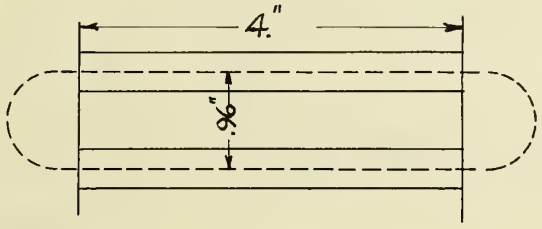
$$= 544 \cdot 1.174 \cdot 4.0 = 2555 \text{ lines}$$

$$E = \frac{4.44 \cdot 1200 \cdot 40 \cdot 4 \cdot 2555}{10^8} = 21.75 \text{ Volts}$$

$$X_1 = \frac{21.75}{30} = 0.725 \text{ ohms.}$$

Resistance of armature.

The stator is to be wound by winding around every other tooth. Then the mean length of each turn will be as shown.



Allow $\frac{1}{4}$" before bending, so as not to break the insulation at the corners, then the length of two straight sides =

$$2 \times 4.5" = 9.0"$$

Length of end connections = $0.96" \pi = 3"$

Then, mean length per turn =

$$9" + 3" = 12" = 1'$$

Total turns in series equals

$$2 \times 40 = 80 \text{ turns.}$$

Total length = $80 \times 1' = 80'$

Resistance of No. 14 wire at 80°C equals 3.12 ohms per 1000 ft.

$R' = 3.12 \times 0.08 = .25$ ohms.

There are, however, four conductors in parallel, so

$$R = \frac{0.25}{4} = 0.0625 \text{ ohms.}$$

Field ampere turns.

Calculated for 90% power factor, inductive.

$X = 1.3$ ohms $\quad X_1 = 0.725$ ohms $\quad R = 0.0625$ ohms.

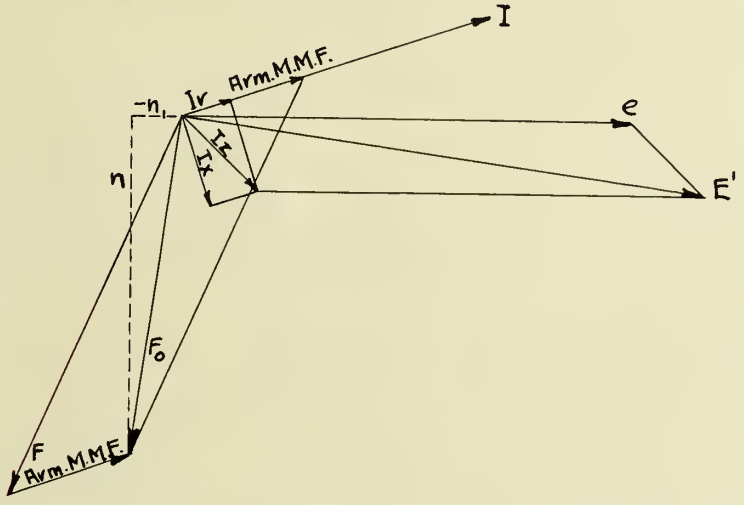
$i = 30$ amperes

$i_1 = 30 \tan(\cos^{-1}.9) = 30 \cdot 0.484 = 14.5$ amperes.

$E' = (e + ir + i_1 x_1) + j(i_1 r - ix)$

$= (100 + 30 \cdot 0.0625 + 14.5 \cdot 0.725) + j(14.5 \cdot 0.0625 - 30 \cdot 1.3)$

$= 112.37 - j\,38.09$



F_0 = resultant ampere turns

F = field ampere turns

Resultant flux is 90° ahead of E', therefore multiply by $(-j)$

$F_0 = -j(+n - jn_1) = -jn - n_1$

$-jn - n_1 = Im + F$

In a single phase machine m equals the number of turns per pole and phase, or

2, in this case. In definite pole machines, such as this one, m is less when used with the power component of current, and is taken as one-half the value used with the wattless component. Call this $m_0 = \frac{m}{2}$. Then,

$$m_0 = \frac{m}{2} = \frac{2}{2} = 1.$$

Then,

$$-jn - n_1 = (i + ji_1)m + \dot{F}$$

$$-jn - n_1 = m_0 i + jmi_1 + \dot{F}$$

$$\dot{F} = -jn - n_1 - m_0 i - jmi_1$$

$$F = \sqrt{-(n_1 + m_0 i)^2 + (n + mi_1)^2}$$

n is taken from the saturation curve as the ampere turns required to give the voltage $(e + ir + i_1 x_1)$ n_1 is taken from the tangent to the curve at that point, and the n_1 is read from the tangent at the voltage $(ix - i_1 r)$

Since the saturation curve of this machine is a straight line,

$$n = \frac{e + ir + i_1 x_1}{e} \cdot 305$$

$$n = \frac{112.37}{100} \cdot 305 = 343 \text{ ampere turns}$$

$$n_1 = \frac{ix - i_1 r}{e + ir + i_1 x_1} \cdot n = \frac{38.09}{112.37} \cdot 343 = 116 \text{ ampere turns}$$

$$F = \sqrt{(116 + 1.30)^2 + (343 + 2 \cdot 14.5)^2}$$

$$= \sqrt{146^2 + 372^2} = 400 \text{ Ampere turns}$$

It was decided to allow 480 ampere turns on the field to allow for overload or slightly smaller power factor with inductive load than 90%. But in case a more inductive load is put on the machine condensers will have to be connected across the terminals of the machine to bring the load close to 90% power factor at the generator, as the field cannot be designed for much more than 480 ampere turns.

Rotor Slots

There are 480 ampere turns to be provided per pole. Allow 6 amperes per conductor. Then,

$\frac{480}{6} = 80$ turns per pole, or

160 conductors per slot.

The slots are to be shaped as shown in drawing, Plate 1, allowing the poles to be of uniform thickness. Let the thickness of the pole equal 0.27", as it could not be made much thinner with safety.

The top of the slot is $\frac{1}{4}$" from the rotor surface, so the circumference there is

$$\pi(12" - 2 \cdot 0.25) = 36.12"$$

$$\frac{36.12"}{40} = 0.903" = \text{width of pole and slot.}$$

$$0.903" - 0.27" = 0.633" = \text{width of slot at top.}$$

Assuming 450 circular mils per ampere

$$450 \times 6 = 2700 \text{ circular mils} = \text{area of wire.}$$

Use No. 16 B.& S. wire, the area of which is 2583 circular mils. Then,

$$\frac{2583}{6} = 430.5 \text{ circular mils per ampere.}$$

Diameter of No. 16 double cotton covered wire = 0.06 inches.

Allow 0.04 inches on all sides of slot for insulation, then width for conductors at top of slot = $0.633" - 0.08" = 0.553"$

$9 \times 0.06 = 0.54''$

By trial it was found that the slot should be 1.47" deep below the wedge, to allow of the admission of the required number of conductors.

The diameter of the rotor at the bottom of the slots equals

$12'' - 2(1.47'' + 0.25'') = 8.56''$

Circumference $= \pi \cdot 8.56'' = 26.9''$

Width of slot $= \frac{26.9''}{40} - 0.27'' = 0.40''$

Depth of conductors =

$1.47'' - 0.08'' = 1.39''$

$\frac{1.39}{0.06} = 23$ wires deep

Width of conductors at bottom,

$0.40'' - 0.08'' = 0.32''$

$\frac{0.32}{0.06} = 5$ conductors

The arrangement of the conductors in the slot will be as shown on drawing, Plate 1, that is,

5 wires 23 deep = 115 conductors
1 wire 21 deep = 21 conductors
1 wire 14 deep = 14 conductors
1 wire 8 deep = 8 conductors

1 wire 2 deep = 2 conductors

Total = 160 conductors

Resistance of Rotor

In this winding every other pole will be wound so the mean length of turn will be from center to center of slot.

Width of slot at center =

$$\frac{0.63" + 0.40"}{2} = 0.515"$$

Width of pole = 0.27"

Length of two sides = 2 x 4.5" = 9., allowing 0.25" at each end before bending wire.

End connections = $\pi(.515" + .27") = 2.46"$

Mean length of turn then equals

9.0" + 2.46" = 11.5" practically.

Total length of wire on rotor is, then,

$$\frac{160 \cdot 20 \cdot 11.5"}{12} = 3060'$$

Resistance of number 16 B.+S. wire equals 4.96 ohms per 1000 ft. at 80° C.

The resistance of the rotor winding is, then,

3.06 · 4.96 = 15.2 ohms.

110 volts would be impressed, so maximum current which could flow equals

$$\frac{110}{15.2} = 7.25 \text{ amperes.}$$

The field would be excited from 110 volts, so with 7.25 amperes maximum current it appears from this value that number 16 is the proper size of wire to use.

$$\frac{110}{6} = 18.3 \text{ ohms}$$

necessary to keep the current down to 6 amperes. So a resistance of

$$18.3 - 15.2 = 3.1 \text{ ohms}$$

will have to be connected in series with the field. A 15 ohm field rheostat would be put in to give a wide control of field excitation.

Iron and I^2R losses.

Rotor.

$R = 15.2$ ohms

$I = 6.0$ amperes

$I^2R = 6^2 \times 15.2 = 547$ watts.

Periphery of slot $= 2 \cdot 1.47" + .63" + .40" = 4.0"$

Radiating surface $= 4.0" \cdot 11.5" = 46.0$ square inches

There are 20 such areas to radiate the heat, so

Total area = $20 \cdot 46.0 = 920$ sq. in.

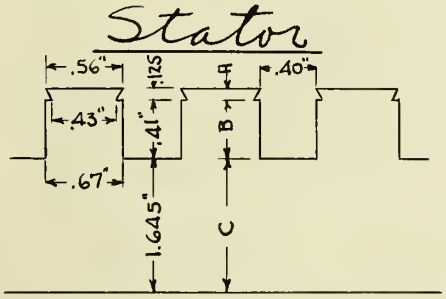
The loss in watts per square inch is

$$\frac{547}{920} = 0.595 \text{ watts}$$

Since the rise in temperature is about 50°C per watt per square inch, the probable rise in temperature of the rotor is

$$50 \cdot 0.595 = 29.8°C.$$

Stator



$\phi = 23460$ lines.

$B_A = \frac{23460}{3.6 \cdot 0.495} = 13190$ lines per sq. in. = 2040 per sq. cm.

$B = \frac{0.56 + 0.67}{2} = 0.615"$

$B_B = \frac{23460}{3.6 \cdot 0.615} = 10610$ lines per sq. in. = 1640 per sq. cm.

$B_C = \frac{23460}{3.6 \cdot 1.645} = 3970$ lines per sq. in = 616 per sq. cm.

Volume at A = $3.6 \cdot 0.495 \cdot 0.125 = 0.223$ cu. in.

Weight at A = $0.223 \cdot 0.283 = 0.0635$ lbs.

Volume at B = $3.6 \cdot 0.615 \cdot 0.41 = 0.955$ cu. in.

Weight at B = $0.955 \cdot 0.283 = 0.269$ lbs.

Volume at C = 3.6 · 1.645 · 1.064 = 6.30 cu. in.

Weight at C = 6.30 · 0.283 = 1.78 lbs.

Hysteresis loss at A = 2.0 · 0.0632 = 0.13 watts

" " " B = 1.6 · 0.269 = 0.43 "

" " " C = 0.6 · 1.780 = 1.068 "

Total hysteresis loss per tooth = 1.628 watts

Hence total hysteresis loss equals

$1.628 \cdot 40 = 65.2$ watts.

At 60 cycles and density equal to B = 64500 lines per square inch the eddy current loss in Apollo iron is 13% of the hysteresis loss. Then at 60 cycles and a density of 10000 lines per square inch eddy loss equals

$$\frac{\left(\frac{1}{6.45}\right)^{1.6}}{\left(\frac{1}{6.45}\right)^{2}} \cdot 0.13 = 6\% \text{ of hysteresis loss.}$$

At 60 cycles hysteresis loss is

$$\frac{65.2}{20} = 3.26 \text{ watts}$$

At 60 cycles eddy current loss equals

$0.06 \cdot 3.26 = 0.216$ watts

At 1200 cycles hysteresis loss is

$20 \cdot 3.26 = 65.2$ watts

At 1200 cycles eddy current loss equals

$$20^2 \cdot 0.216 = 86.4 \text{ watts.}$$

Allow double this eddy current loss to allow for burrs and blisters and poor construction. So total iron loss equals

$$175 + 65 = 240 \text{ watts.}$$

As developed on page 9 the resistance of the stator winding is 0.0625 ohms. Then I^2R loss equals

$$30^2 \cdot 0.0625 = 56 \text{ watts.}$$

Hence total loss in stator, iron and copper, is

$$240 + 56 = 296 \text{ watts}$$

The surface available to radiate this heat, as seen on plate 2, is

$$17 \cdot \pi \cdot 4 + 12 \cdot \pi \cdot 4 + \left(17^2 \cdot \frac{\pi}{4} - 12.2^2 \frac{\pi}{4}\right) 2 = 591 \text{ sq. in.}$$

Then

$$\frac{296}{591} = 0.50 \text{ watts per sq. in.}$$

The temperature rise is about 80°C per watt per square inch of surface. So probable rise equals

$$0.50 \cdot 80 = 40°\text{C.}$$

Centrifugal Force.

Volume of pole =

$(0.644 \cdot 0.125 \cdot 3.6) + (0.457 \cdot 0.125 \cdot 3.6) + (0.27 \cdot 1.47 \cdot 3.6) =$

1.926 cu. in.

Weight of pole =

$1.926 \cdot 0.283 = 0.545$ lbs.

Weight of number 16 wire is 7.81 lbs. per 1000 ft. Mean length of turn = 11.5"

Total length of wire supported by one pole equals

$$\frac{80 \cdot 11.5}{12} = 76.6 \text{ ft.}$$

Weight = $7.81 \cdot 0.076 = 0.585$ lbs.

Total weight = $0.545 + 0.585 = 1.13$ lbs.

Centrifugal force equals $\frac{WRN^2}{2933}$, where

W = weight in pounds

R = radius, to centre of gravity, in feet.

N = R.P.M. (from Kent page 423.)

$$F = \frac{1.13 \cdot 0.434 \cdot 3600^2}{2933} = 2160 \text{ lbs.}$$

Ultimate strength of steel = 55000 lbs. per square inch.

Resisting area = $4.0 \cdot 0.9 \cdot 0.27 = 0.972$ sq. in.

Ultimate strength equals

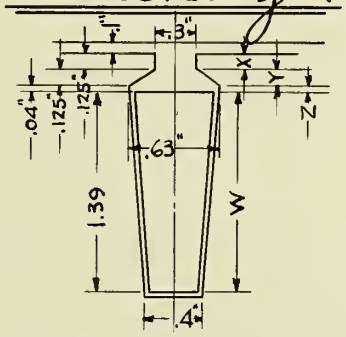
$55000 \cdot 0.972 = 53400$ lbs.

Hence factor of safety equals

$$\frac{53400}{2160} = 24.7$$

which shows that the design is safe.

Leakage.



$$L_X = \frac{0.2}{0.3} \cdot \frac{0.125}{0.6} = 13.9\%$$

$$L_Y = \frac{0.2}{0.485} \cdot \frac{0.125}{0.6} = 8.6\%$$

$$L_Z = \frac{0.2}{0.63} \cdot \frac{0.04}{0.6} = 2.0\%$$

$$L_W = \frac{0.2}{0.53} \cdot \frac{1.39}{3 \cdot 0.6} = 29.2\%$$

Total leakage equals 53.7%

Flux in air gap equals 23460 lines.

Hence flux in pole equals

$$23460 \cdot 1.54 = 36200 \text{ lines.}$$

Hence flux density equals

$$\frac{36200}{0.972} = 37300 \text{ lines per square inch, or}$$

$$B = \frac{37300}{6.45} = 5780 \text{ lines per sq. cm.}$$

Regulation.

Since the saturation curve is a straight line, the regulation may be computed directly from the field ampere turns. For 90% power factor, lagging current, the ampere turns were computed as being 400. For 100 volts, zero load, 305 ampere turns are needed, so

$$E_o = \frac{400}{305} \cdot 100 = 131.1 \text{ volts}$$

Hence, the regulation, which is defined as the rise in voltage when the load is thrown off, is

$$\frac{131.1 - 100.0}{100} = 31.1\%$$

Similarly, for non-inductive load,

$$E_o = \frac{345}{305} \cdot 100 = 113.1 \text{ Volts.}$$

Hence, regulation equals

$$\frac{113.1 - 100}{100} = 13.1\%$$

The compounding curves, which are equivalent to the regulation curves when the saturation curve is a straight line, and the calculations for same for various power factors are shown at the end of this thesis.

Efficiency.

The efficiency can be only approximately estimated, as the core loss, friction loss, and windage loss cannot be accurately determined. The eddy current loss will depend to a great extent on the smoothness of the stampings, as blisters will increase this loss quite materially. The core loss as calculated was increased almost 100% to make liberal allowance for this, so the efficiency as calculated will probably be too low rather than too high.

From tests run on the induction motor, the frame of which will be used for this alternator, the friction and windage loss was found to be about 25 watts. The speed in this case was 1200 R.P.M., and as the windage loss is small as compared with the friction loss at ordinary speeds, the friction loss was probably about 20 watts and the windage 5 watts. The friction loss varies directly as the speed, so at 3600 R.P.M. it would be

$$3 \cdot 20 = 60 \text{ watts.}$$

The windage varies as the cube of the speed

so it would be

$$3^3 \cdot 5 = 135 \text{ watts}$$

This would make the friction and windage loss equal to about 200 watts.

In calculating the field loss the rheostat is charged to the machine, and as the field is to be excited from 110 volt mains the field loss will be 110 · field current.

On this basis the losses at full load, unity power factor will be :-

Field loss $= 110 \cdot \frac{345}{80} = 475$ watts.

Stator loss $= I^2R = 30^2 \cdot .0625 = 56.2$ watts

Iron loss = 240 watts

Friction and windage = 200 watts

Total loss = 971.2 watts

At full load the output equals 3000 watts, hence

Input $= 3000 + 971 = 3971$ watts.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{3000}{3971} \cdot 100 = 75.6\%$$

Calculations and curves showing losses and efficiencies at various loads and unity power factor are shown at the back of this thesis.

General Description.

The frame for this machine may be ordered from the General Electric Co., as it is the frame of their 5 H.P., type L1, 60 cycle, 110 volts, 1200 R.P.M., induction motor, so a description of this feature is not needed. Detail drawings of the parts changed are included in this thesis, and these drawings are self explanatory. The rotor and stator stampings are to be of a standard thickness, 14 mils, and all corners are to be rounded and not left sharp. The stampings should be varnished before assembling.

As the speed of this machine is high the rotor should be perfectly balanced. In order that this may be done pockets are to left on the spokes of the spider, as shown on Plate I, some of which may be filled with lead if the rotor does not balance after it has been assembled.

A hole is to be drilled in the shaft, as shown, to bring the field connections out to the slip rings. The openings through which these wires enter and leave the shaft should have all sharp corners

rounded off, so there is no danger of cutting the insulation from the wires, and thus causing a short circuit.

The rotor and stator will both have to be wound by hand, and in both cases every other tooth being wound. The rotor winding will all be in series, but in the stator there are to be four wires in parallel. These stator windings should come out to two pairs of binding posts, making two separate armature windings which may be connected either in series or parallel. By this arrangement full voltage can be generated at half speed.

The slip rings to be used are of the type used by the General Electric Co. on their small rotating field alternators, and are shown on Plate I. The wedges in the slots are to be of hard maple, and, since the centrifugal forces acting on the end connections of the rotor are quite large, the wedges should extend about one-half inch beyond the end of the slots. The end plates, shown on Plate I, are to be made of 14 or 16 gauge steel, and

are to be fastened to the rotor clamping rings, but held away from them by means of bushings. These plates will tend to force a stream of air past the ends of the windings and also through the slots, hence cooling the machine.

REGULATION – POWER FACTOR = 1.00

I	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0
i	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0
i_1	0	0	0	0	0	0	0	0	0	0
ir	3.13	2.81	2.50	2.18	1.87	1.51	1.25	0.94	0.62	0.31
i_1x_1	0	0	0	0	0	0	0	0	0	0
$e+ir+i_1x_1$	103.1	102.8	102.5	102.2	101.9	101.5	101.3	100.9	100.6	100.3
ix	65.0	58.5	52.0	45.5	39.0	32.5	26.0	19.5	13.0	6.5
i_1r	0	0	0	0	0	0	0	0	0	0
$ix-i_1r$	65.0	58.5	52.0	45.5	39.0	32.5	26.0	19.5	13.0	6.5
$\frac{ix-i_1r}{e+ir+i_1x_1}$	0.630	0.570	0.507	0.445	0.383	0.320	0.257	0.193	0.129	0.065
n	315.0	314.0	313.0	312.0	311.0	310.0	309.0	308.0	307.0	306.0
mi_1	0	0	0	0	0	0	0	0	0	0
$n+mi_1$	315.0	314.0	313.0	312.0	311.0	310.0	309.0	308.0	307.0	306.0
n_1	198.0	179.0	159.0	139.0	119.0	99.3	79.5	59.5	39.6	19.9
m_oi	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0
n_1+m_oi	248.0	224.0	199.0	174.0	149.0	124.3	99.5	74.5	49.6	24.9
F	401.0	386.0	371.0	357.0	345.0	334.0	325.0	317.0	311.0	307.0
E_o	131.6	126.6	121.7	117.0	113.1	109.5	106.5	103.9	101.9	100.8

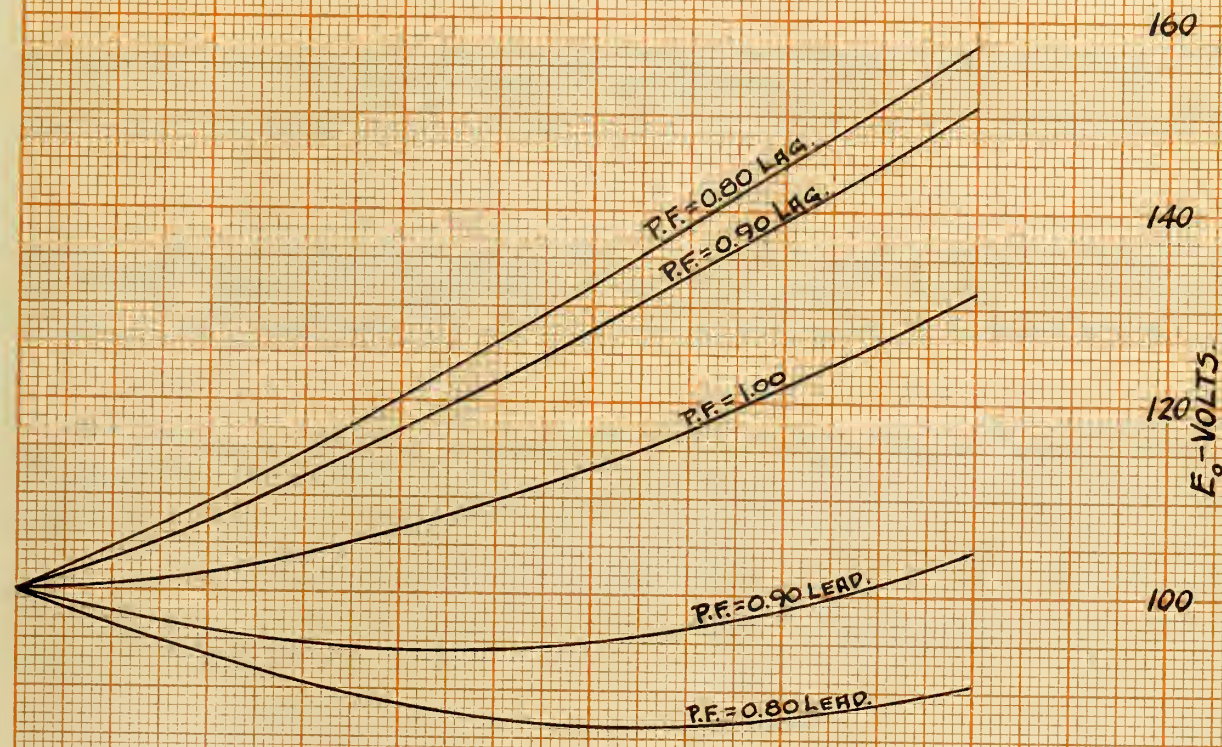
$e = 100$ Volts.
$r = 0.0625$ Ohms.
$x = 1.30$ Ohms.
$x_1 = 0.725$ Ohms.
$m = 2.$
$m_o = 1.$

REGULATION — POWER FACTOR = 0.90 LAG.										
I	50.0	44.5	38.9	33.3	27.8	22.2	16.7	11.1	5.56	0
i	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0	0
i_1	21.8	19.4	16.9	14.5	12.1	9.70	7.30	4.80	2.40	0
ir	2.81	2.50	2.18	1.87	1.51	1.25	0.94	0.63	0.31	0
i_1x_1	15.8	14.1	12.2	10.5	8.77	7.02	5.28	3.51	1.75	0
$e+ir+i_1x_1$	118.6	116.6	114.4	112.4	110.3	108.3	106.2	104.1	102.1	100.0
ix	58.5	52.0	45.5	39.0	32.5	26.0	19.5	13.0	6.5	0
i_1r	1.36	1.21	1.06	0.91	0.76	0.61	0.46	0.30	0.15	0
$ix-i_1r$	57.1	50.8	44.4	38.1	31.7	25.4	19.0	12.7	6.35	0
$\frac{ix-i_1r}{e+ir+i_1x_1}$	0.482	0.436	0.388	0.339	0.281	0.234	0.179	0.122	0.062	0
n	362.0	356.0	349.0	343.0	337.0	331.0	324.0	318.0	312.0	305.0
mi_1	43.6	38.8	33.8	29.0	24.2	19.4	14.6	9.6	4.8	0
$n+mi_1$	405.6	394.8	382.8	372.0	361.2	350.4	338.6	327.6	316.8	305.0
n_1	174.0	155.0	135.0	116.0	94.9	77.5	58.0	35.4	19.3	0
m_0i	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0	0
n_1+m_0i	219.0	195.0	170.0	146.0	119.9	97.5	73.0	45.4	24.3	0
F	461.0	440.0	419.0	400.0	379.0	364.0	346.0	331.0	318.0	305.0
E_0	151.0	144.2	137.3	131.1	124.2	119.2	113.4	108.4	104.2	100.0

REGULATION – POWER FACTOR = 0.80 LAG.										
I	56.2	50.0	43.7	37.5	31.2	25.0	18.7	12.5	6.25	0
i	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0	0
i_1	33.7	30.0	26.2	22.5	18.7	15.0	11.2	7.5	3.75	0
$i_1 x_1$	24.8	22.0	19.2	16.5	13.7	11.0	8.05	5.44	2.72	0
ir	2.81	2.50	2.18	1.87	1.51	1.25	0.94	0.63	0.31	0
$e+ir+i_1x_1$	127.6	124.5	121.4	118.4	115.2	112.2	109.0	106.0	103.0	100.0
ix	58.5	52.0	45.5	39.0	32.5	26.0	19.5	13.0	6.5	0
$i_1 r$	2.1	1.9	1.6	1.4	1.1	0.9	0.7	0.5	0.2	0
$ix - i_1 r$	56.4	50.1	43.9	37.6	31.4	25.1	18.8	12.5	6.3	0
$\frac{ix - i_1 r}{e+ir+i_1x_1}$	.442	.402	.361	.317	.272	.224	.172	.118	.061	0
n	389.0	380.0	370.0	361.0	352.0	342.0	332.5	323.0	314.5	305.0
mi_1	67.5	60.0	52.5	45.0	37.5	30.0	22.5	15.0	7.5	0
$n+mi_1$	456.5	440.0	422.5	406.0	389.5	372.0	355.0	338.0	322.0	305.0
n_1	172.0	153.0	133.5	114.2	95.8	76.7	57.2	38.1	19.2	0
$m_0 i$	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0	0
$n_1 + m_0 i$	217.0	193.0	168.5	144.2	120.8	96.7	72.2	48.1	24.2	0
F	506.0	480.0	455.0	431.0	408.0	384.0	362.0	341.0	323.0	305.0
E_0	166.0	157.5	149.2	141.3	133.8	126.0	118.6	111.8	105.9	100.0

REGULATION – POWER FACTOR = 0.90 LEAD										
I	50.0	44.5	38.9	33.3	27.8	22.2	16.7	11.1	5.56	0
i	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.00	0
i_1	21.8	19.4	16.9	14.5	12.1	9.70	7.30	4.80	2.40	0
ir	2.81	2.50	2.18	1.87	1.51	1.25	0.94	0.63	0.31	0
i_1x_1	15.8	14.1	12.2	10.5	8.77	7.02	5.28	3.51	1.75	0
$e+ir-i_1x_1$	87.1	88.4	89.9	91.4	92.7	94.2	95.7	97.1	98.6	100.0
ix	58.5	52.0	45.5	39.0	32.5	26.0	19.5	13.0	6.5	0
i_1r	1.74	1.2	1.1	0.9	0.8	0.6	0.5	0.3	0.2	0
$ix+i_1r$	59.9	53.2	46.6	39.9	33.3	26.6	20.0	13.3	6.7	0
$\frac{ix+i_1r}{e+ir-i_1x_1}$	0.687	0.603	0.518	0.437	0.359	0.283	0.209	0.137	0.067	0
n	265.0	269.6	274.0	278.5	282.5	287.4	291.8	298.0	300.0	305.0
mi_1	43.6	38.8	33.8	29.0	24.2	19.5	14.6	9.6	4.8	0
$n-mi_1$	221.4	230.8	240.2	249.5	258.3	267.9	277.2	288.4	295.2	305.0
n_1	184.0	162.0	142.0	122.0	101.0	81.4	61.0	40.9	20.2	0
m_0i	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0	0
n_1+m_0i	229.0	202.0	177.0	152.0	126.0	101.4	76.0	50.9	25.2	0
F	319.8	306.5	298.7	292.0	287.5	286.7	287.5	292.9	296.2	305.0
E_0	104.7	100.4	98.0	95.8	94.3	94.1	94.3	96.0	97.2	100.0

REGULATION – POWER FACTOR = 0.80 LEAD.										
I	56.2	50.0	43.7	37.5	31.2	25.0	18.7	12.5	6.25	0
i	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.00	0
i_1	33.7	30.0	26.2	22.5	18.7	15.0	11.2	7.5	3.75	0
ir	2.81	2.50	2.18	1.87	1.51	1.25	0.94	0.63	0.31	0
i_1x_1	24.8	22.0	19.2	16.5	13.7	11.0	8.05	5.44	2.72	0
$e+ir-i_1x_1$	78.0	81.5	83.0	85.4	87.8	90.2	92.9	95.2	97.6	100.0
ix	58.5	52.0	45.5	39.0	32.5	26.0	19.5	13.0	6.50	0
i_1r	2.11	1.87	1.64	1.41	1.13	0.94	0.70	0.47	0.23	0
$ix+i_1r$	60.6	53.9	47.1	40.4	33.6	26.9	20.2	13.5	6.73	0
$\frac{ix+i_1r}{e+ir-i_1x_1}$	0.778	0.662	0.569	0.473	0.384	0.299	0.218	0.142	0.069	0
n	237.8	248.3	253.0	260.1	267.5	274.8	283.0	290.0	297.5	305.0
mi_1	67.5	60.0	52.5	45.0	37.5	30.0	22.5	15.0	7.5	0
$n-mi_1$	170.3	188.3	200.5	215.1	230.0	244.8	260.5	275.0	290.0	305.0
n_1	185.0	164.0	144.0	123.0	103.0	82.2	61.8	41.2	20.5	0
m_0i	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0	0
$n+m_0i$	230.0	204.0	179.0	153.0	128.0	102.2	66.8	51.2	25.5	0
F	286.0	277.0	269.0	264.0	263.0	265.0	272.0	280.0	291.0	305.0
E_0	93.8	90.9	88.2	86.6	86.3	86.9	89.2	91.9	95.5	100.0



160
140
120
100
80

E_0 - VOLTS.

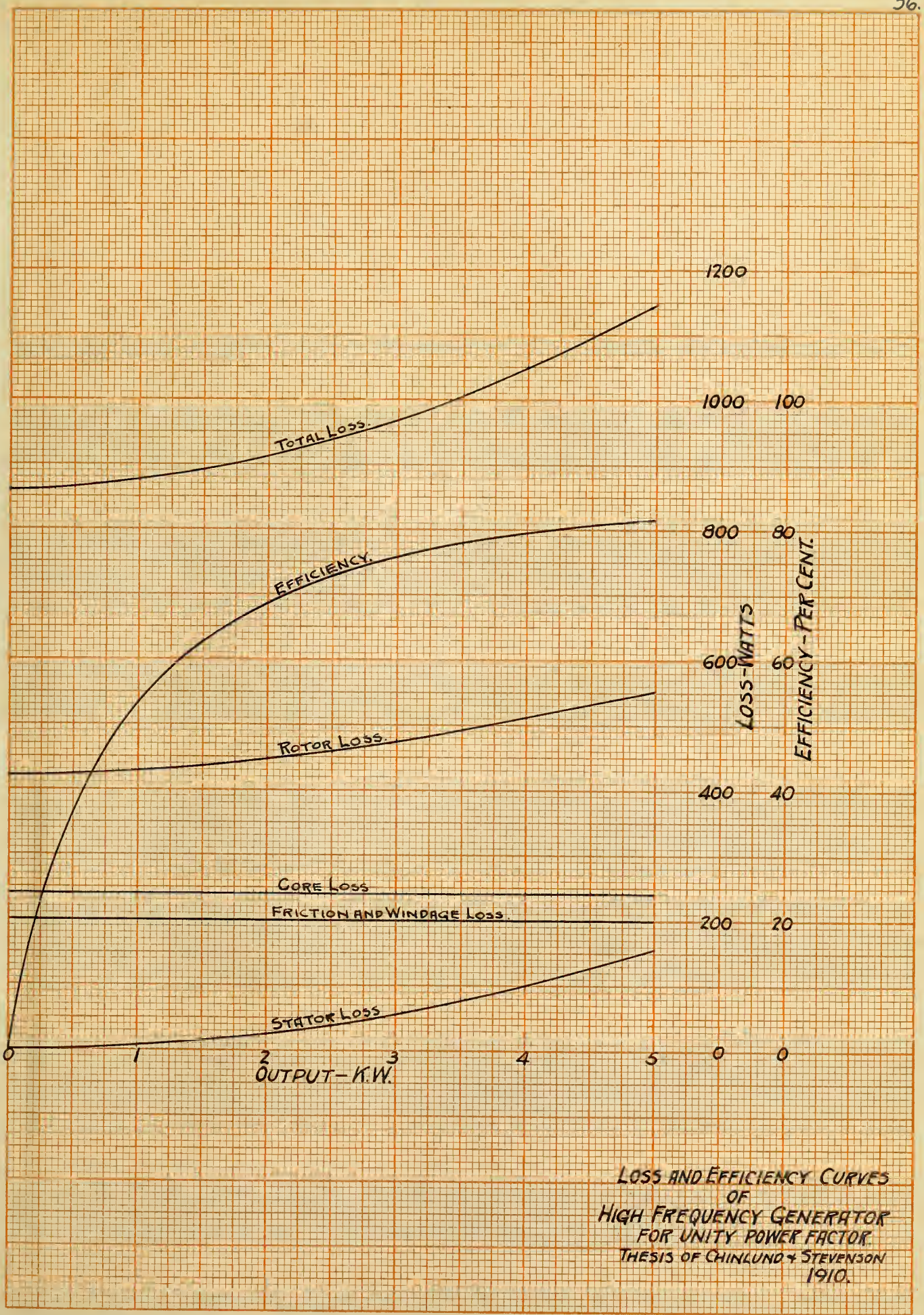
10 20 30 40 50

LOAD - AMPERES

COMPOUNDING CURVES
OF
HIGH FREQUENCY GENERATOR.
THESIS OF CHINLUND & STEVENSON.
1910.

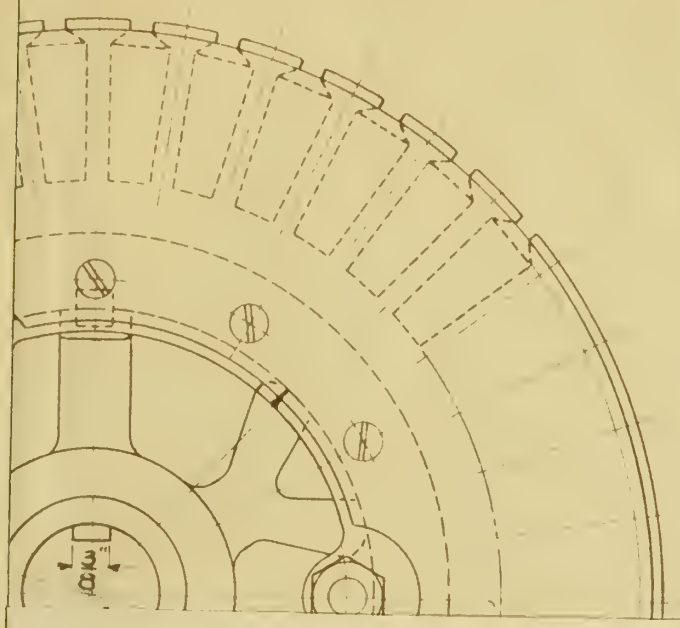
U. OF I. S. S. FORM 3

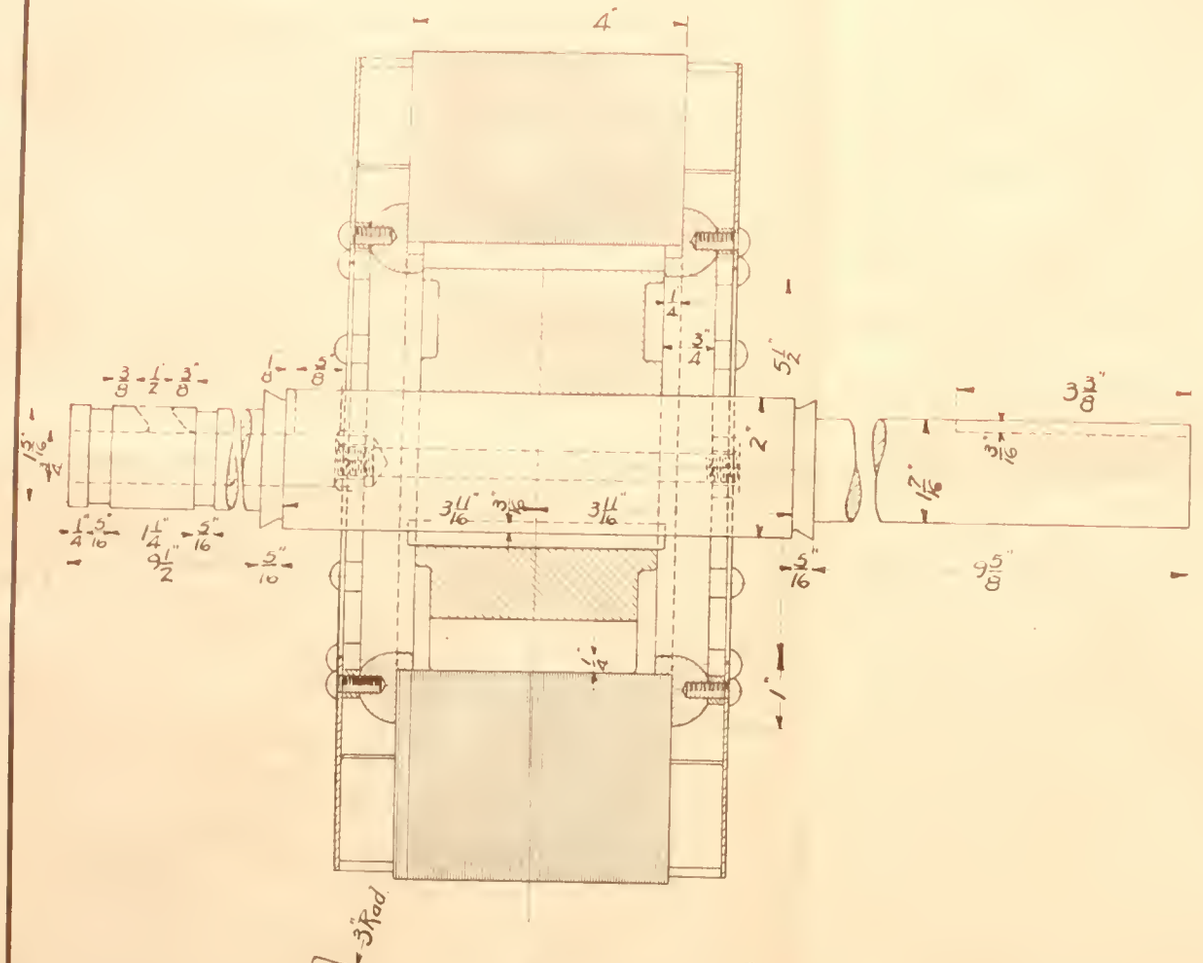
EFFICIENCY – POWER FACTOR = 1.00										
CURRENT	50.0	45.0	40.0	35.0	30.0	25.0	20.0	15.0	10.0	5.0
FIELD I^2R	551.0	531.0	510.0	491.0	475.0	459.0	447.0	436.0	428.0	422.0
STATOR I^2R	156.0	126.5	100.0	76.5	56.2	39.0	25.0	14.5	6.2	1.5
IRON	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
FRICTION AND WINDAGE.	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0
TOTAL LOSS	1147.	1097.	1050.	1007.	971.	938.	912.	890.	874.	863.
OUTPUT.	5000	4500	4000	3500	3000	2500	2000	1500	1000	500
INPUT.	6147	5597	5050	4507	3971	3438	2921	2390	1874	1363
EFFICIENCY	.815	.809	.793	.776	.756	.729	.687	.628	.534	.366

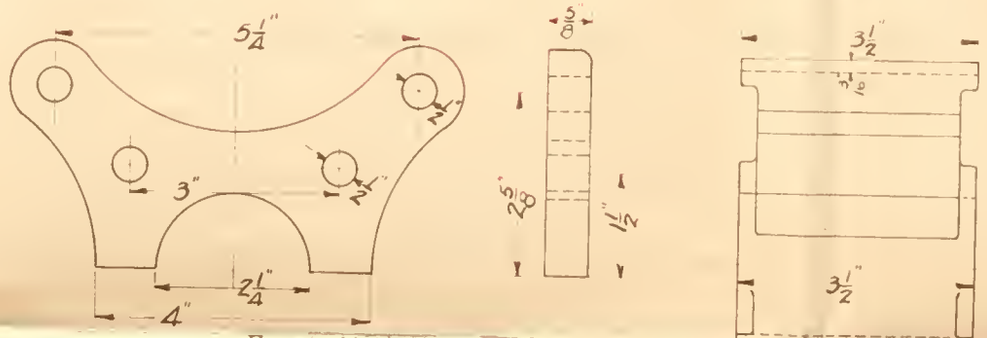


LOSS AND EFFICIENCY CURVES
OF
HIGH FREQUENCY GENERATOR
FOR UNITY POWER FACTOR.
THESIS OF CHINLUND & STEVENSON
1910.

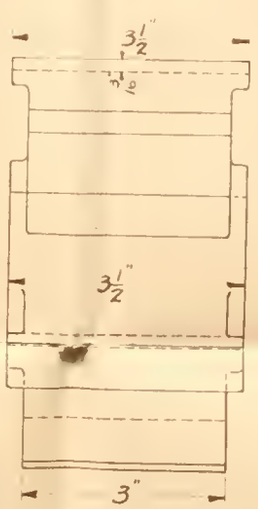
U. OF I. S. S. FORM 2

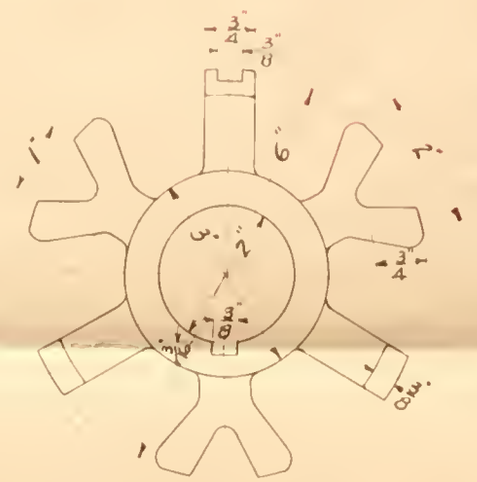




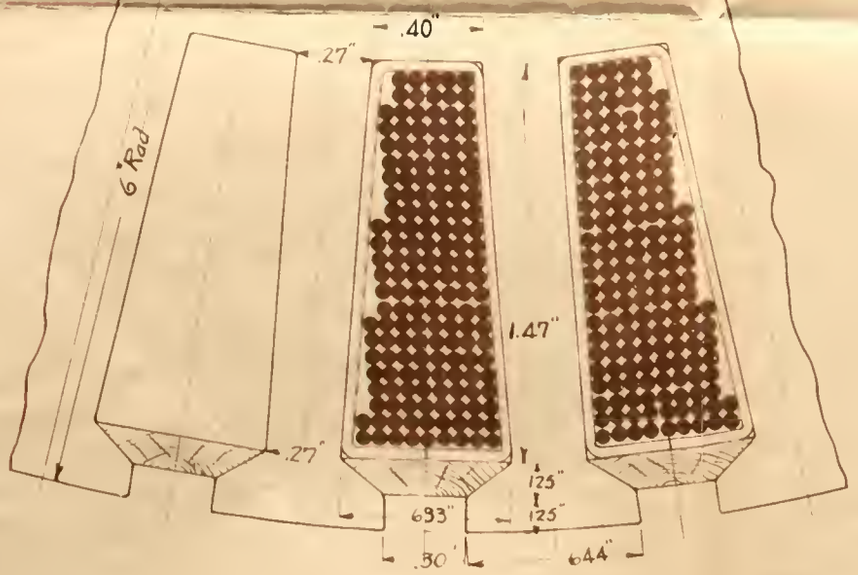


Brush Holder Support
Cast Iron.

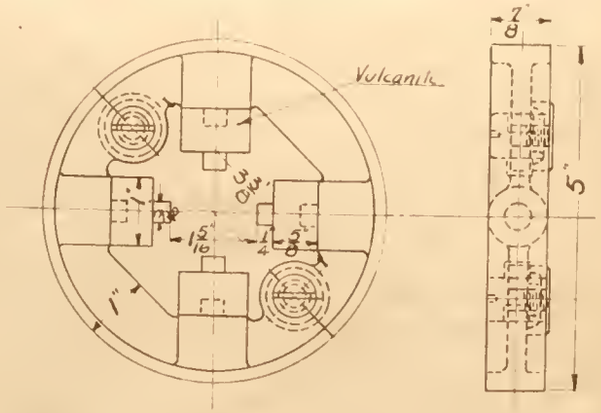




Spider
Cast Iron



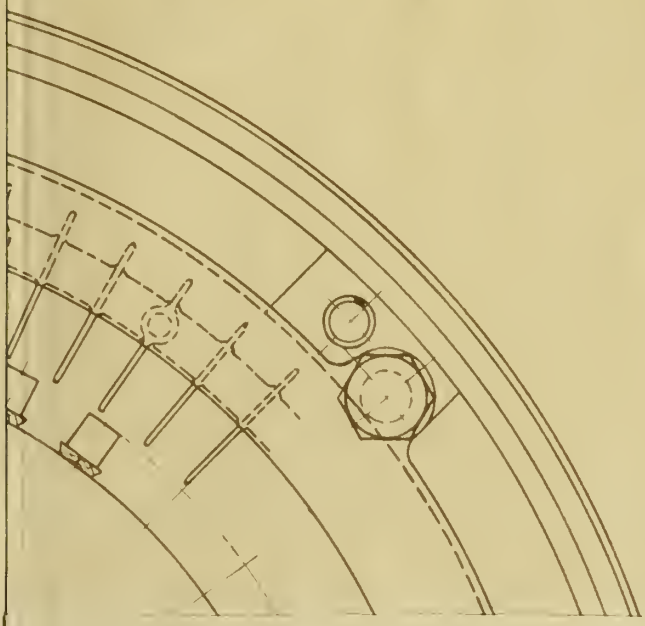
Rotor Slots.
40 Slots - 160 Conductors
per slot - 16 gauge D.C.C wire
Scale 24" = 1 Ft.

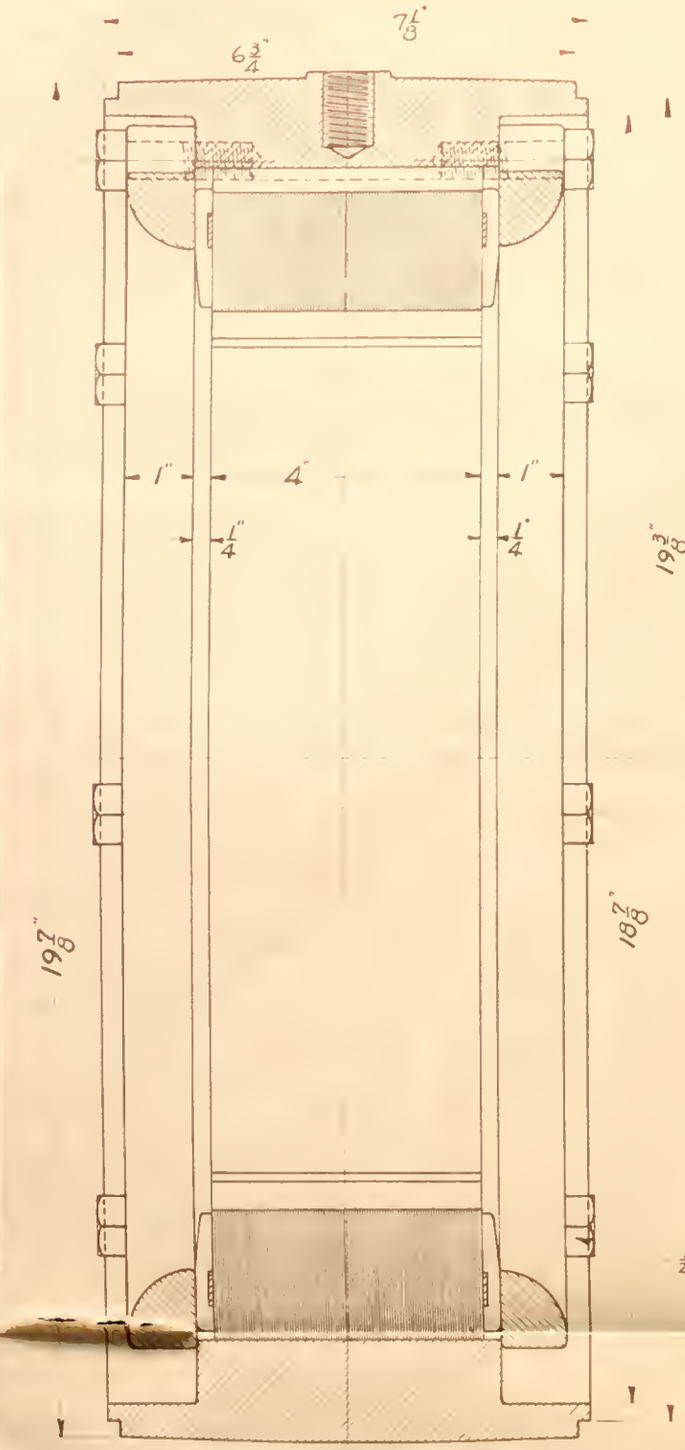


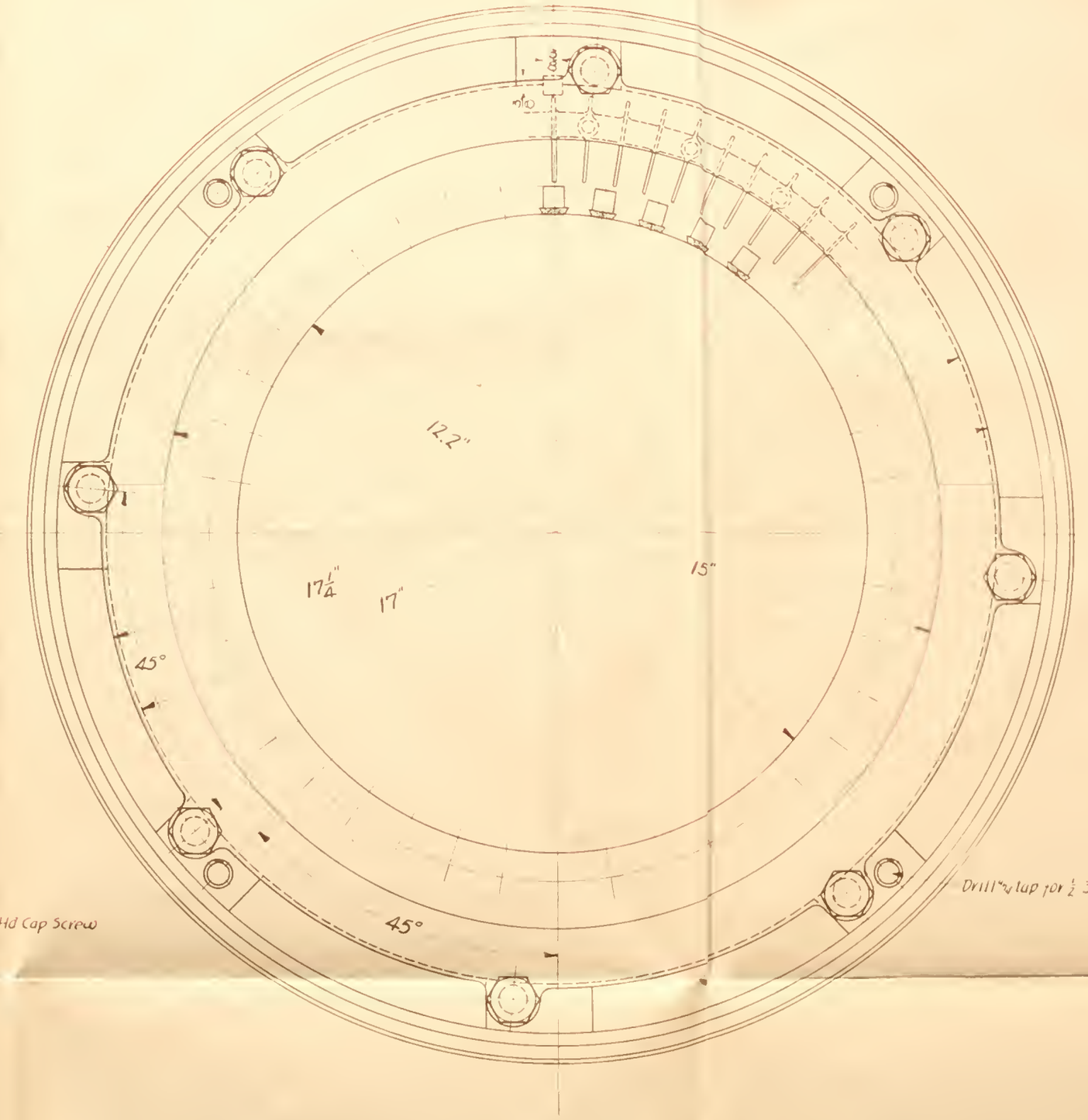
Collector Ring
Cast Iron.

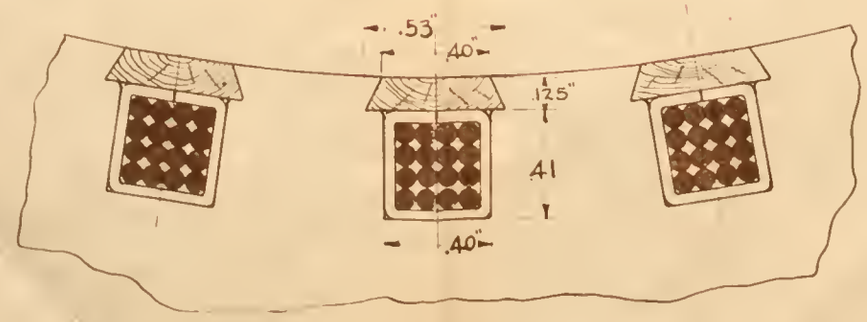
ELECTRICAL ENGINEERING DEPARTMENT.
UNIVERSITY OF ILLINOIS
THESIS
DESIGN OF A HIGH FREQUENCY GENERATOR
ROTOR
SCALE 6" = 1' EXCEPT AS SHOWN
J.F. CHINLUND & J.R. STEVENSON CLASS OF 1910.

PLATE I.





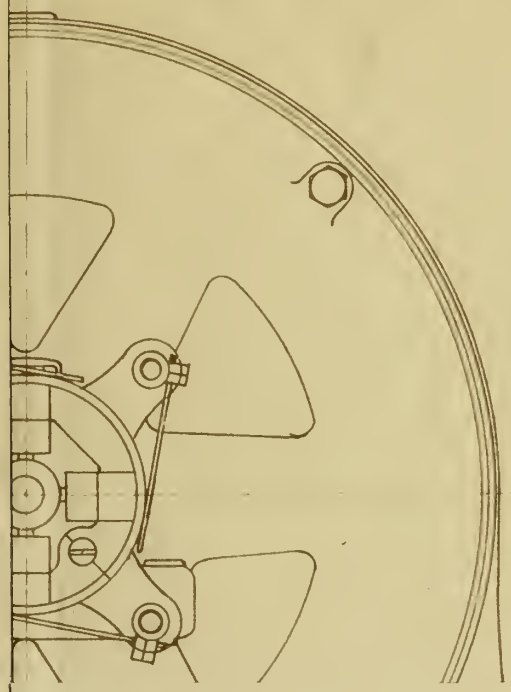


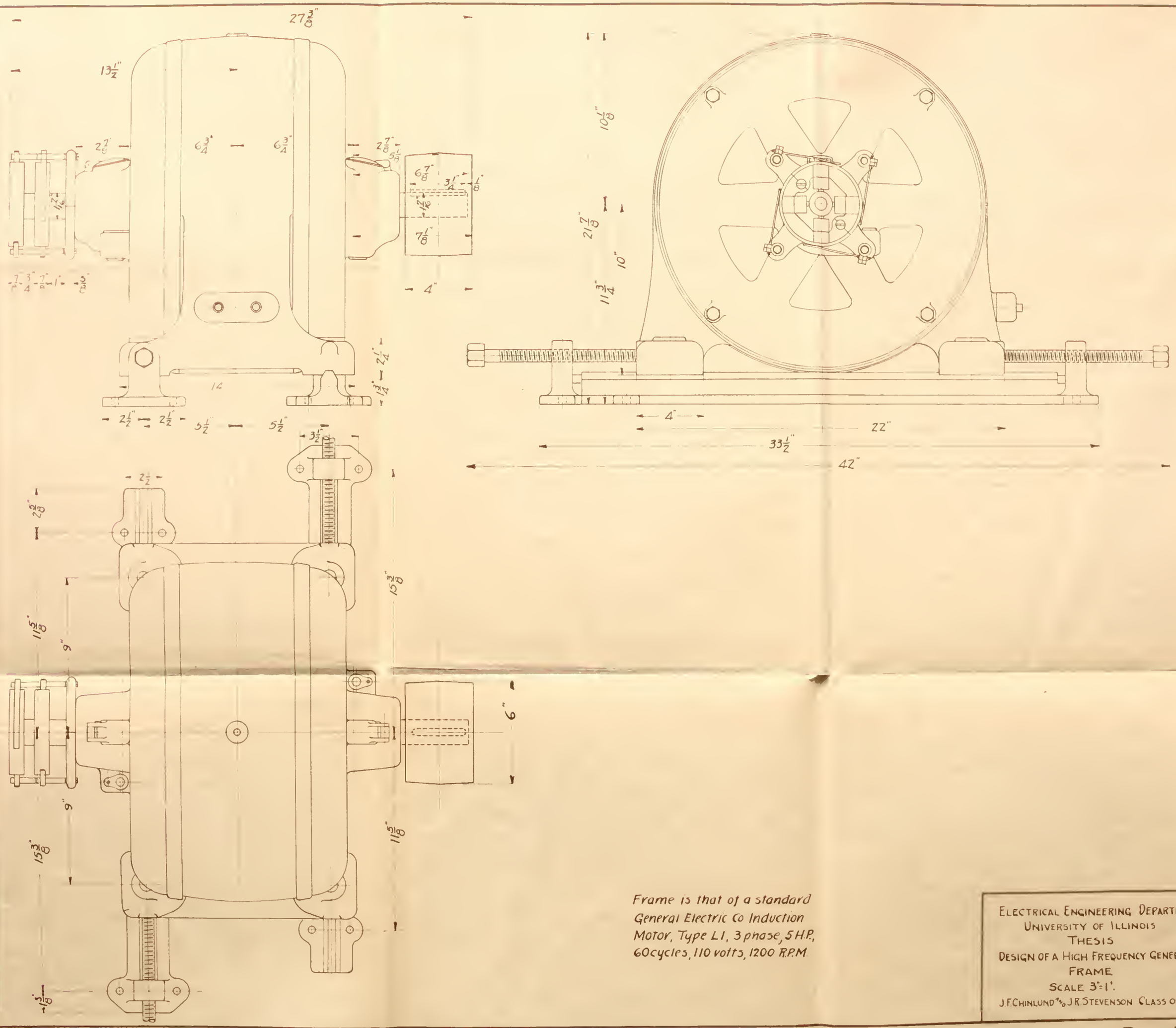


Stator Slots.
40 Slots - 16 Conductors
per Slot - No 14 gauge DCC wire
Scale:- 24" = 1'

ELECTRICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ILLINOIS
THESIS
DESIGN OF A HIGH FREQUENCY GENERATOR
STATOR
SCALE 6" = 1' EXCEPT AS SHOWN
J F CHINLUND AND J R STEVENSON. CLASS OF 1910.

PLATE 2.





Frame is that of a standard General Electric Co Induction Motor, Type L1, 3 phase, 5 H.P., 60 cycles, 110 volts, 1200 R.P.M.

ELECTRICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ILLINOIS
THESIS
DESIGN OF A HIGH FREQUENCY GENERATOR
FRAME
SCALE 3"=1'.
J.F. CHINLUND & J.R. STEVENSON CLASS OF 1910

PLATE 3.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 086826432